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A Review on Converters of Electric Vehicles

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ABSTRACT

The majority of vehicles are electrifying. Nowadays, conventional vehicles (Internal Combustion Engine) emit significant amounts of carbon dioxide and carbon monoxide, contributing to environmental pollution. Electric vehicle is one of the solutions to reduce emissions. Electric vehicles rely heavily on power electronics. They serve as a link between the power grid and the battery. Fast charging can be accomplished through the development of power converters. Power electronics can contribute to the advancement and expansion of electric vehicle manufacturing. The use of front-end (AC-AC Converters) and back-end (DC-DC Converters) converters in electric vehicles is being investigated here. Various converters are compared according to output voltage required. Power electronics can solve the problems associated with battery charging. The major challenges include enhancing the driving range, battery life and power capability. The energy management control strategy plays a vital role in regulating the power flow as per the drive cycle load requirement. This necessitates an efficient control design to accommodate real-time load fluctuations by regulating the power flow from the hybrid sources. There has been advancement and continuous development in power electronic converter topologies. The converter topology and energy management control schemes will open up fresh avenues in hybridizing energy sources for EV applications.

Keywords: *Power electronics, Electric vehicles, battery chargers, Front-end and Back-end converters.*

1. INTRODUCTION

As fossil fuels degrade and new eco-friendly technologies emerge, we have adopted a new technology by electrifying our vehicles. A conventional vehicle (IC Engine) emits a lot of gases, which contribute to the greenhouse effect [4]. The deployment and development of electric vehicles is an alternative method for avoiding the greenhouse effect and reducing the use of fossil fuels. The government has implemented some policies to encourage people to buy EVs, such as tax breaks on vehicle purchases and exemptions from road tolls. As fuel prices rise, more people will opt for electric vehicles. Despite advancements in EV technology, there are still some potential barriers to widespread adoption, such as charging infrastructure, converter topologies, battery degradation, and driving range issues [1]. Lower operating costs and improved fuel economy are the primary reasons for EV popularity. Electric vehicles can be combined with renewable energy sources (RES) such as wind turbines, solar panels, and fuel cells. To achieve fast battery charging, there is a significant need for new power converters with low cost and high reliability for EV's advance charging mechanism. In EVs, various types of converters are used. Front end converters are those that convert an alternating current supply to a direct current supply [4]. Back-end converters are those that convert DC power to DC power. As illustrated in Fig. 1. Dust and construction cause 45% of pollution, waste burning causes 17%, transportation causes 14%, diesel generators cause 9%, industries cause 8%, and domestic cooking causes 7%. Electric vehicles are an alternative way to avoid pollution. Converters serve as a link between the power grid and the battery. As the number of EVs grows, so do the challenges associated with power converters [1]. This paper investigates the challenges associated with isolated and non-isolated DC-DC converters, as well as front-end converters.

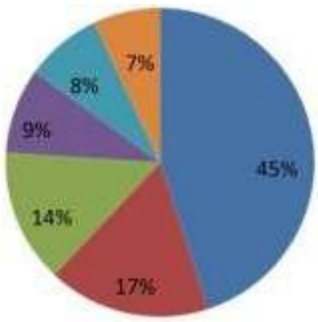

Fig 1.1: Sources of air pollution in India

Reasons to Choose an Electric Vehicle:

- Lower operating costs
- Better fuel economy
- Reduced Carbon emission
- Peak load sharing
- Revenue generation
- Tracking of Renewable energy sources

Requirement of Converters in Electric Vehicles:

In electrical vehicle charging, the power electronics converter is critical for charging the battery with voltage and current regulation. The majority of power electronics converters are semiconductor-based and are used to charge batteries with low voltage to high voltage and high voltage to low voltage conversion. Controlled semiconductor switches such as SCR, BJT, Power MOSFET, IGBT, and others perform the conversion operation [1].

EV Battery Charging:

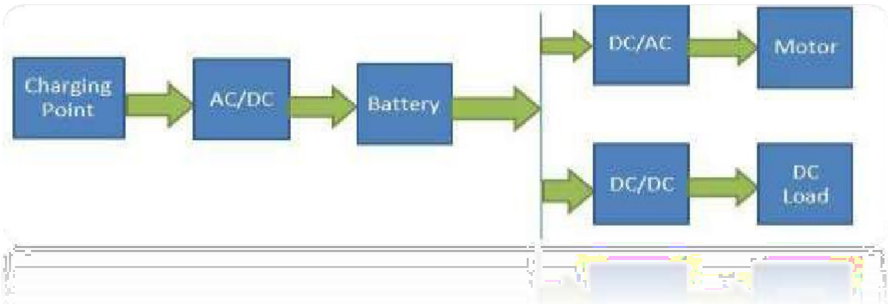

Fig 1.2: Basic Block Diagram of Electric Vehicle

To achieve the requirements, electric vehicles use various types of converters. The Electric Vehicle block diagram is shown in Fig 1.2. An electric vehicle is equipped with two batteries: a main battery and an auxiliary battery. When we charge using the mains, we receive an AC supply. Using a rectifier, this AC supply is changed to a DC supply, which is then used to charge the main battery. Since the motor used in EV designs is an AC motor, an inverter must be installed between the motor and the DC bus. An auxiliary battery is charged using a DC-DC converter [1].

2. AC-DC Converter:

AC-DC converter is used to convert AC voltage to DC voltage which is usually known as a rectifier. The supply voltage available is of alternating (AC) and the AC voltage cannot be stored in the battery so in order to run the electric vehicle for a long a distance a battery is required so we convert the AC supply to DC supply. The rectifier used in the circuit can be an uncontrolled or controlled one. As the battery is connected to the supply mains there is a chance of injecting of harmonics into the circuit. To remove the harmonics Power Factor correction (PFC) [8] techniques are implemented. PFC techniques make the supply current to be in phase with the supply voltage. In order to achieve the unity power factor, the PFC technique is placed in parallel with the rectification. The PFC senses the inside current and voltage and according to this it, turn-on or turn-off the switches in the circuit. One of the desired aspects is to convert AC-DC by using minimum number of switches. We can use a three phase two stage AC-DC power converter or we can place the three single phase units [1]. One of the main drawbacks with the three single phase unit [8] is to make all three units to be synchronized and the triple harmonics are not eliminated where as in the three-phase converter naturally the 3rd harmonic and its multiples can be removed. Vienna rectifier is an AC-DC converter has higher reliability, low cost, lower Electro Magnetic Interface (EMI), higher power density. The control of Vienna rectifier is complex than that of conventional six switch converters. Diodes are used for soft switching and to minimize the recovery losses and to achieve high efficiency reverse recovery diodes are used.

Front End Converters:

These converters convert the AC supply which is taken from the utility mains to DC supply [9]. While injecting this AC power to an Electric Vehicle current-harmonics are generated. Power Factor Correction techniques (PFC) technique is used to avoid current-harmonics. PFC technique can make input current to be sinusoidal and in phase with the supply voltage and power (PF) nearly to one. PFC technique senses the input voltage and current and turn-on (or) turn-off the switches so that input currents to be sinusoidal and in phase with voltage [10].

Issues in AC-DC Conversion

- Power factor
- Cost issues
- Complications in control circuitry.
- Efficiency
- Total harmonic distortion

Conventional method of converting AC-DC is by using six switches and connecting capacitor as a dc link so that constant voltage appears across the main battery. Some of techniques have been implemented to convert AC to DC by reducing the number of switches. But the controlling of these switches became difficult. Vienna rectifier is a circuit which is used to rectify the AC voltage. Scientists have implanted the two-stage conversion i.e., AC-DC and DC-AC into single stage in one block but the control of this circuit becomes somewhat difficult. For low power applications 3 phase single switch converters are simpler, cheaper and better solution. An algorithm is required to keep voltage and current to be in-phase. Digital Processing (DSP) kit is used for implementer's algorithm. The simplest AC to DC converter is by convention boost rectifier [1]. For high power techniques we go with inter leaved technique.

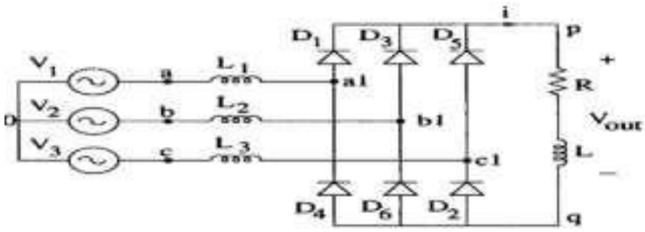

Fig 2.1: Conventional AC-DC Converter

3. Classification of DC-DC Converter:

Non-isolated DC-DC converters and isolated DC-DC converters are the two types of DC-DC converters based on their galvanic isolation. Figure 1 depicts the classification of many types of DC-DC converters [1].

- **Isolated Converter:** These converters use transformer-based topologies. In the power path, a transformer offers ground isolation.
- **Non-Isolated Converter:** These converters have no transformer and no isolation between the source and the ground.

Fig 3.1: Types of Power converters for converting DC-DC

Non-Isolated Bidirectional DC-DC Converter (NIBDC):

This converter doesn't use a high-frequency transformer to provide electrical isolation between the power supply and the load. As a result, for safety considerations, NIBDC DC-DC converters are only used in low-power applications [2]. These converters are efficient since they are simple to control and lower in weight because they lack a transformer for galvanic isolation.

Buck Converter:

Other isolated converters, such as forward, flyback, half bridge, and full bridge, are known as "Buck Converters," and they are all implemented using a conventional DC-DC converter circuit. It is a voltage converter. This converter connects the primary battery and the supplemental battery. Because a primary battery is normally (200-400 V) and an auxiliary battery is (14 V), a buck converter is used to step down the main battery voltage to 14 V and charge the auxiliary battery. This auxiliary battery provides electricity to loads like as power steering, wipers, lighting, and audio/video systems. It has the most basic configuration with the fewest parts. The inductor filters out ripples in the load current, whereas the capacitor filters out ripples in the output voltage. One of the main drawbacks of the buck converter is its short duty cycle, which limits its use to high-power applications [1].

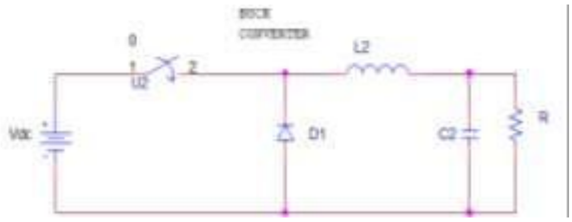

Fig 3.2: Circuit of Buck Converter

Boost Converter:

This converter is used to boost the direct current voltage. It is installed between the AC machine and the main battery. The motor requires 600 V, but the voltage available is (200-400 V), so a boost converter is utilized to enhance the voltage to 600 V. It can step increase voltage without converting it to alternating current and a transformer, then rectifying the transformer output. It is not intended for high-power conversion [1] and can only step a minimal amount of DC voltage.

Fig 3.3: Circuit of Boost Converter

Buck-Boost Converter:

It is a DC-DC bidirectional converter. This converter is also referred to as an energy management [4] converter. It can step up and step down the voltage based on the needs of the vehicle. This converter is connected to the DC bus and the main battery. It has fewer components than other converters and is bidirectional, meaning it can supply power to (or take power from) the grid. It necessitates a larger filter size and has a higher incidence of electromagnetic interface issues (EMI) [6]. The non-isolated bidirectional DC-DC converter lacks isolation from input to output, which may cause damage to the circuit under abnormal conditions. It is difficult to manage. This converter is used to reduce current ripples in the battery and maintain constant DC link voltage, allowing the power train to operate at high power levels. As a battery's state of charge (SOC) decreases [10], so does its voltage and the available voltage at the inverter. A bidirectional DC-DC converter is used to keep the voltage at the inverter constant. The presence of this converter allows the DC bus voltage to maintain a constant torque, avoiding fluctuations during the transition from motoring to braking. This converter keeps small ripples [1].

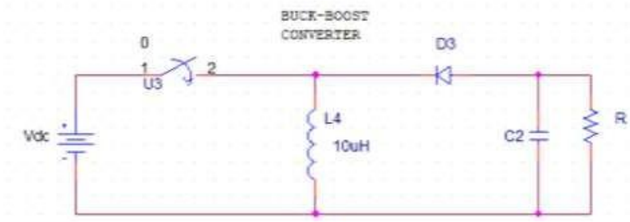

Fig 3.4 Buck-Boost Converter

CUK Converter:

This converter is similar to a buck-boost converter, which is used to increase or decrease voltage [2]. The only difference between a buck-boost converter and a Cuk converter is that the output voltage polarities are inverted. The output voltage is inverted with respective to the supply voltage.

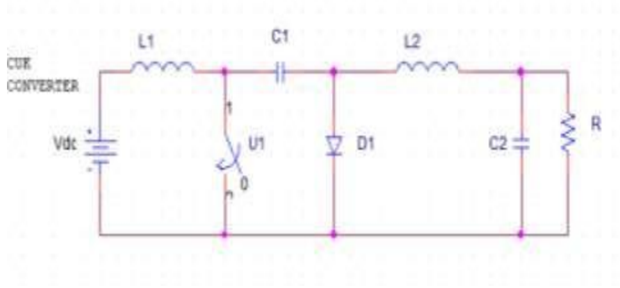

Fig 3.5 Circuit of CUK Converter

SEPIC Converter:

A bi-directional non-isolated DC-DC converter having a Single-Ended Primary Inductor. It is a non-inverting buck-boost converter. The gate-driven circuit of this converter is simple. The input current of this circuit is not pulsing [1]. It is subjected to less voltage stress compared to a CUK converter.

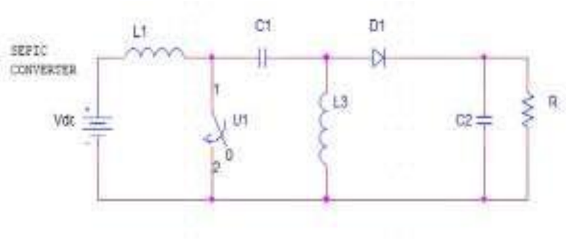

Fig 3.6 Circuit of SEPIC Converter

4. Isolated Converter:

It is a type of bidirectional DC-DC converter in which a high-frequency transformer is used to provide isolation between the input and load [6]. The Transformer might have an impact on the entire cost and cause additional losses. There are numerous isolated converter topologies available, including half-bridge, full-bridge, forward converter, and flyback converter [9]. These converter topologies provide the following significant advantages:

- Galvanic isolation
- The number of components is reduced due to the use of fewer active switching devices.

Forward Converter:

This converter is analogous to a bidirectional DC-DC converter. The voltage can be stepped up or down using this converter. Ripple currents can be removed by using an inductor, and a constant voltage can be maintained across the load by using a capacitor [1]. Voltage stress on the secondary side of a transformer is greater than voltage stress on the primary side. The polarities of the load remain unchanged during this operation. The transformer primary has the same polarities as the secondary, which means that both the primary and secondary are twisted in the same way.

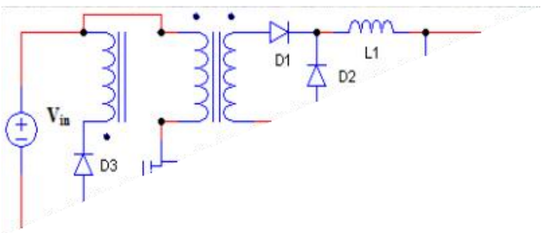

Fig 4.1: Circuit for Forward Converter

Flyback Converter:

It is a bidirectional isolated DC-DC converter. It has the ability to step up or step down the voltage. This converter requires fewer components. The primary and secondary windings of a transformer are twisted in opposite directions so that opposite polarities are induced on the windings. Due to the lack of an inductor, this converter cannot remove current ripples [6].

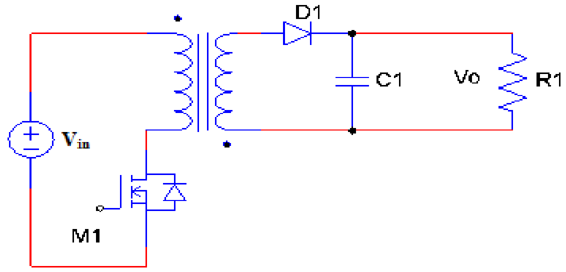

Fig 4.2: Circuit for Flyback Converter

Half Bridge Converter:

It is also a bidirectional isolated DC-DC converter. The secondary side of the half bridge construction is the same as the secondary side of a push pull converter. As more capacitors are placed across the supply voltage, the ripples in the supply voltage are removed [9]. As the secondary is centre tapped, half of the voltage is induced, reducing stresses on the secondary winding. Switching must be properly controlled. If switching is not properly controlled, there is a risk of a short circuit on the primary side.

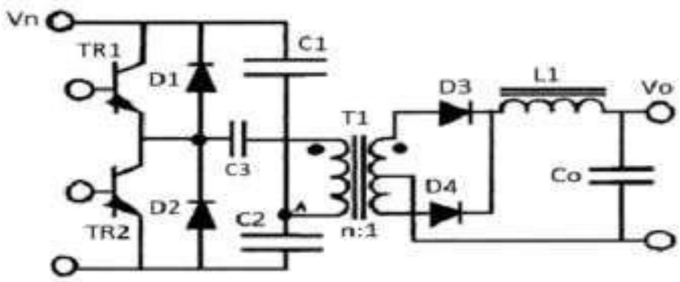

Fig 4.3: Circuit for Half Bridge Converter

Full Bridge Converter:

It is an isolated bi-directional DC-DC Converter [1]. The construction is same as of half bridge converter with some basic changes. The number of switches used in this converter is more compared to that of half bridge converter. The circuit complexity and switching losses in the circuit will be increased. A proper control over switching is required. If there is any mismatch in switching it leads to the short circuit [9].

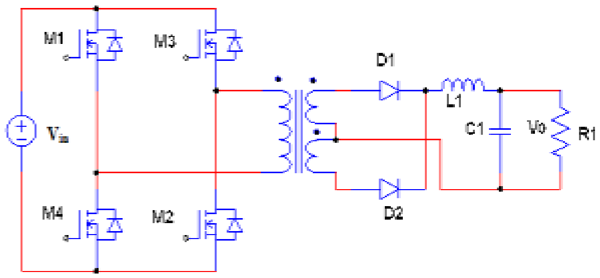

Fig 4.4 Circuit for Full Bridge Converter

Table 1: Comparison of various converters:

S. No	Name of the Converter	Components Required	Properties
1	Buck Converter	Fewer	• Used in self-regulating power supplies.
2	Boost Converter	Fewer	• Used in regulating power supplies

3	Bidirectional DC-DC converter	More	• Used in Electric vehicle to control and maintain constant DC bus voltage**.**
4	Flyback Converter	Fewer	• Input current is pulsating. • Applications require isolation conversion can use Flyback converter. • Higher current and voltage stresses. • Work as either inverting or non-inverting converter
5	Forward Converter	More	• Step up or Step down the voltage. • Input current is pulsating. • Low cost.
6	SEPIC Converter	Less	• Non-Inverting buck-boost • Less voltage stresses compared to CUK. • Input current is non- pulsating. • Designing of gate drive circuit is simple.
7	CUK Converter	More	• Inverting converter (negative polarity at the output). • Reduces ripple current at input and output. • Continuous current at input and output.
8	Half Bridge Converter	Less	• Conduction and Switching losses are less. • Transformer core is effectively utilized. • Step up or Step-down converter. • More stress on the components.
9	Full Bridge Converter	More	• Stress on the component is less. • Control of theses circuit is complex. • Higher conversion ratio and higher power levels.

Conclusion:

This paper, presents a comprehensive review on power electronic converters used in Electric vehicles. It also, provides the different techniques of energy management by the advancement increase in power electronic converters improve the charging solution of electric vehicles. By using efficient power converter, the overall efficiency of the system can be improved. An extensive analysis of front-end and back-end converters along with their benefits and issues is presented. Power factor correction techniques are used to remove the harmonics and resonant circuits are used to reduce switching losses. By the advancement in power electronic converters the overall efficiency of the system and a fast charging can be achieved with in short period of time which makes the user to save the time for charging his battery during travelling long distances.

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